Using MMX™ Instructions to Implement 2D Sprite Overlay

Information for Developers and ISVs

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1.0. INTRODUCTION

The Intel Architecture (IA) media extensions include single-instruction, multi-data (SIMD) instructions. This application note presents examples of code that exploits these instructions.

Sprites are computer characters which generally appear in the foreground. They are implemented by overlaying small sprite images on a large background image. Characters do not cover the entire sprite image, which is usually rectangular, so some parts of the image are transparent.

Methods for implementing sprites differ depending on the application. The MMX™ technology. Sprite Overlay function described here uses a read-modify-write approach. The function reads the background under the sprite from video memory and uses the new pcmpeqb instruction to construct a mask which permits the background to show through transparent regions of the sprite image. Eight sprite pixels and eight background pixels are combined with the MMX instruction sequence pcmpeqb, pand and por without any branches. This function writes only in the region covered by the sprite.

This approach to implementing sprites cannot be used in systems with video cards which do not permit reading directly from video memory. In systems in which direct access is permitted the approach works best for a single small sprite because reading from video memory is slow. When more than one sprite are implemented those in back must be written first so that if sprites overlap those in front will overwrite appropriate parts of sprites in back by treating them as background.

More complex applications implement sprites differently. One approach used in applications with several sprites is to write the entire scene from back to front every time. Only valid sprite pixels are written. If a sprite does not change the number of branches can be reduced by branching to a location which represents several branches. This can be done with codes which indicate which sprite pixels are valid. For example, there are sixteen possible combinations of valid and not valid pixels for a group of four pixels. Branching to one of sixteen locations which represents a sequence of valid and not valid values eliminates three out of four branches. Further information about sprites is available in *Zen of Graphics Programming* by Michael Abrash, and *Tricks of the Game Programming Gurus* by LaMothe, Ratcliff, Seminatore and Tyler.

2.0. SPRITE OVERLAY FUNCTION

The overlay function is one of several functions called by a sprite engine to control sprites.

2.1. Sprite Engine

The skeleton of a simple sprite engine for a single sprite which describes how an overlay function is related to other sprite functions is shown in Example 1. There are two basic phases in the main loop of this engine for a single sprite. The first of these is the control phase, and the second is the draw phase. The control phase determines when, where, and what to draw, and the draw phase restores the original background which the sprite has overwritten and redraws the sprite with the overlay function. The engine in Example 1 makes a character appear alive by moving and animating it. The sprite is moved by drawing it in a different location on the background, and it is animated by drawing a different frame so parts of its body appear to move. This simple engine animates the sprite by drawing the next frame in a sequence. Sophisticated sprite engines take into account factors such as collisions with features in the background and other sprites and 3D modeling.

More than one sprite can be implemented in the sprite engine in Example 1 by changing the structure of the main while loop so there is an outer loop with an inner loop which replaces the background followed an inner loop which draws the sprites with the Sprite Overlay function. The Sprite Overlay pseudocode function and the corresponding sprite_overlay MMX function call save the background behind the sprite in a buffer before the sprite is written, so the background can be restored. If there are several sprites the background of a sprite may include part of a sprite behind it. Therefore, the loop which restores the background should draw the backgrounds saved in buffers from front to back, and the loop which overlays the sprites should draw the sprites from back to front.

Example 1. Skeleton of a Simple Engine for a Single Sprite

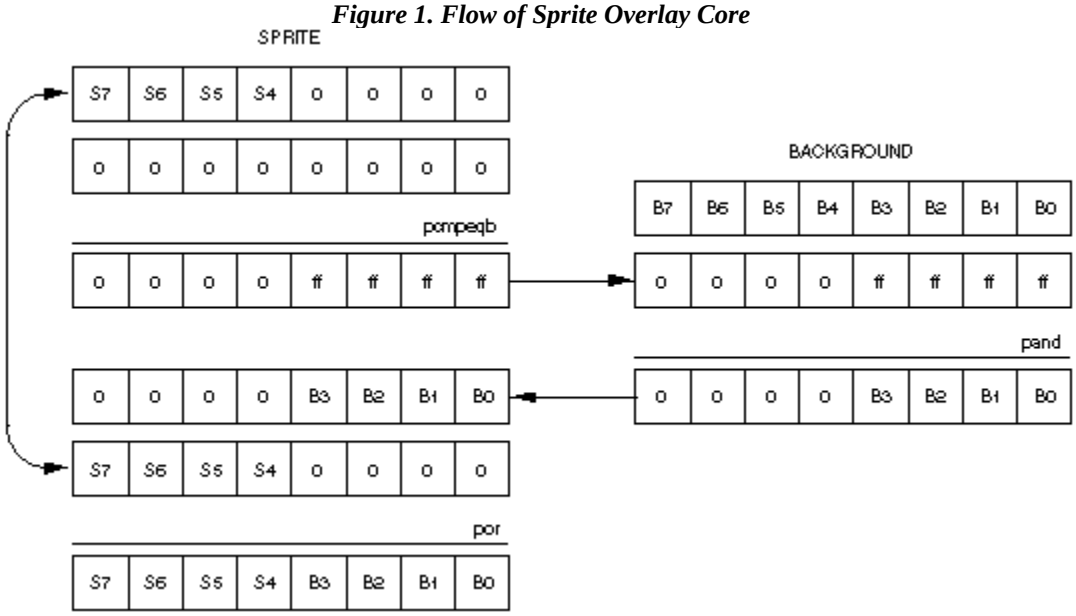
```
//Some Structures
typedef struct image_type {
//information about images and a pointer to the image buffer
}Image, *ImagePtr;
type struct sprite_type
        int x_cur, y_cur;              //current position
        int x_old, y_old;              //previous position
        int width, height;             //sprite size
        int move_period, move_count;   //loops until moved
        int animate_period, animate_count; //loops per frame
        int frame_total, frame_count //frame currently displayed
        char * sprite_background;    //background under sprite
        char * frame[NumberSpriteFrames];
        int state;
}Sprite, *SpritePtr;

//Some Variables
Image  background, sprites;
Sprite thesprite;
//Display Sprite
main()
{
        //Initialize
        SetVideoMode(mode);    //set VGA card mode
```

```
        //Read in background image and display it on the screen.
        AllocateBuffer((ImagePtr)&background, ScreenWidth*ScreenHeight);
        LoadBuffer("background.dat",(ImagePtr)&background);
        DecompressBuffer((ImagePtr)&background);
        PaletteToVGA((ImagePtr)&background);
        DisplayBuffer((ImagePtr)&background, ScreenWidth*ScreenHeight);
        FreeBuffer((ImagePtr)&background);
        //Initialize sprite structure. Transfer sprite images from large image.
        AllocateBuffer((ImagePtr)&sprites, NumberSpriteFrames*
                SpriteWidth*SpriteHeight);
        LoadBuffer("sprites.dat",(ImagePtr)&sprites);
        DecompressBuffer((ImagePtr)&sprites);
        InitializeSpriteMotion((SpritePtr)&current_frame, x, y,
                move_period, move_count,animate_period, animate_count);
        InitializeSpriteFrames((ImagePtr)&sprites,
                (SpritePtr)&theprite, NumberSpriteFrames);
        FreeBuffer((ImagePtr)&sprites);
        //Save background under  sprite, and draw the first sprite frame.
        SpriteOverlay((SpritePtr)&thesprite);
        //Main Loop
        while(thesprite.state == ALIVE) {
                if(++thesprite.animate_count >          //test for draw new frame
                        thesprite.animate_period) {
                        thesprite.animate_count = 0; //reset animation counter
                        if(++frame_count > frame_total) {
                                thesprite.frame_count = 0;  }//reset frame number
                        draw_flag = 1;
                }
                if(++thesprite.move_count > thesprite.move_period)    {
                        thesprite.move_count = 0;  //reset move counter
                        move_flag = draw_flag = 1;
                }
                if(move_flag) { //determine where to draw the sprite
                        SpritePosition((SpritPtr)&thesprite);  //update position
                        if(thesprite.state == DEAD) draw_flag = 0;
                }
                if(draw_flag) {
                        ReplaceBackground((SpritePtr)&thesprite);
                        SpriteOverlay((SpritePtr)&thesprite);
                        draw_flag = move_flag = 0;  //reset flags
                }
        }
}
```

2.2. Sprite Overlay Core

Figure 1 illustrates the flow of MMX instructions used to draw sprite pixels which are not transparent. Transparent pixels have values equal to zero. The example shows a case in which the lower 4 bytes (those on the right) are transparent and the upper 4 are not transparent. The first step sprite data are compared with mask data equal to zero using the pcmpeqb instruction. In cases in which the corresponding bytes of sprite data are zero, the mask data are changed to ff, and in cases in which the corresponding bytes of sprite data are not zero, the mask data remain equal to zero. The second step the mask and background data are combined with the pand instruction. This step retains background data in locations where the sprite data is zero, and sets background data equal to zero in locations where sprite data is not zero. The third step the sprite and background data are combined with the por instruction.

Figure 1. Flow of Sprite Overlay Core



The core of the sprite overlay code is listed in Example 2. Sprite data is loaded in instruction 3 and background data is loaded in instruction 5. Values of the mask are initialized to zero in instruction 4, and values are set to ff where the sprite is transparent in instruction 6. In instruction 8 mask values which were equal to ff are set equal to values of the background data, and mask values which were equal to zero remain zero. Sprite data and background data are combined in instruction 10, and written to the video buffer in instruction 12. Background data which is overwritten by sprite data is saved in instruction 11.

Background data is saved so that the background can be restored when the sprite is moved.

Example 2. Sprite Overlay Core

```
LoopTop:

1       add     ebx, 8          ;counter for buffer region under sprite
2       add     ecx, 8          ;counter for video address to write sprite
3       movq    mm0, [eax]      ;read sprite
4       pxor    mm7, mm7        ;zero in mm7 which is the mask
5       movq    mm1, [ecx]      ;read background under sprite
6       pcmpeqb mm7, mm0        ;make mask where sprite is transparent
7       add     eax, 8          ;counter for sprite buffer
8       pand    mm7, mm1        ;pixels of region under sprite to draw

9       add     ebp, 8          ;increment inner loop counter
10      por     mm7, mm0        ;combine sprite and background
11      movq    [ebx], mm1      ;save background overwritten by sprite

12      movq    [ecx], mm7      ;write sprite
13      cmp     ebp, edi        ;done with current sprite row?
14      jne     LoopTop
```

3.0. PERFORMANCE GAINS

Several factors make comparison of the MMX technology performance and scalar performance of sprite overlay functions difficult. One factor is reading video data is system dependent. A second factor is that sprite overlay functions tend to be optimized for the application for which they are written, so sprite overlay performance varies from application to application.

3.1. Scalar Performance

A section of scalar code which handles the transparency problem in a manner similar to the MMX code in Example 2 is shown in Example 3. The loop processes four pixels. This code does not represent optimized scalar code which would be used to implement sprites. Rather it contrasts the efficiency of scalar code and MMX code when scalar code implements sprite overlay in a manner similar to the method used by the MMX code presented here.

Example 3. Scalar Sprite Overlay Core

```
Position0:
        mov     eax, [ebx]              ;4 pixels sprite data
        mov     ecx, [edx]              ;4 pixels background data to ecx
        xor     ebp, ebp                ;0->ebp. ebp holds sprite overlay results
        mov     [edi], ecx              ;store background
        add     ebx, 4                  ;increment sprite address
        mov     esi, 0x000000ff         ;load mask
        and     esi, eax                ;determine if pixel is transparent
        jz      Position1               ;jump to position 1 if transparent
        or      ebp, esi                ;first pixel of sprite in sprite overlay
        jmp     Position2               ;do the next pixel
Position1:
        mov     esi, 0x000000ff         ;reload mask

        and     esi, ecx                ;first pixel of background in esi

        or      ebp, esi                ;background in sprite overlay
        add     edi, 4                  ;increment background address
        mov     [edx], ebp              ;write sprite overlay
        add     edx, 4                  ;increment video address
        cmp     ebx, LAST_SPRITE_ADDRESS
        jnz     Position0
```

.2. MMX™ Technology Performance

Instructions in the inner loop take eight clocks to execute which is equivalent to one clock per pixel if reading from video memory is not taken into account.

Misaligned 64-bit accesses have a three clock penalty. The code presented here does nothing to avoid this problem. Misalignment can often be avoided, but there is a generally a cost. For example, instead of a single sprite image for a particular sprite there could be eight images each with the valid pixels shifted with respect to each other along rows. The sprite engine would choose the sprite with no misalignment penalty. Costs of this method include one additional pass through the overlay loop each row because the width of the sprite would increase, overhead to determine which sprite to call and memory required for seven extra sprite images.

MMX technology benefits are due to several factors:

- MMX technology adds the pcmpeqb instruction which avoids conditional branches.
- MMX technology permits single instruction multiple data (SIMD) operations.
- MMX technology adds the 64-bit movq instruction which reduces memory stalls when loading non-cacheable video data.
- MMX technology adds registers reducing register pressure.

4.0. SPRITE OVERLAY CODE LISTING

```
;sprite overlay
;This function assumes that the width of the sprite is divisible by 8
        TITLE testmmx
        .486
.model FLAT
PUBLIC _sprite_overlay
_DATA SEGMENT
_DATA ENDS
_TEXT SEGMENT
_spritePtr$    = 8            ;the sprite
_backPtr$      = 12           ;buffer to save region under sprite
_videoPtr$     = 16           ;video buffer with large background
_offset_video$ = 20           ;offset from beginning of video buffer
_width_screen$ = 24           ;width of large background image
_width_sprite$ = 28
_height_sprite$= 32
_sprite_overlay PROC NEAR
        push ebp
        mov ebp, esp
        push eax
        push ebx
        push ecx
        push edx
        push esi
        push edi

        mov ecx, _videoPtr$[ebp]
        mov edi, _offset_video$[ebp]
        mov edx, _width_screen$[ebp]
        add ecx, edi

        mov eax, _spritePtr$[ebp]
        mov ebx, _backPtr$[ebp]
        mov edi, _width_sprite$[ebp]
        mov esi, _height_sprite$[ebp]

        sub edx, edi
        xor ebp, ebp

        sub ebx, 8
        sub ecx, 8
LoopTop:

        add     ebx, 8          ;counter for buffer region under sprite
        add     ecx, 8          ;counter for video address to write sprite
        movq    mm0, [eax]      ;read sprite
        pxor    mm7, mm7        ;zero in mm7
        movq    mm1, [ecx]      ;read background under sprite
        pcmpeqb mm7, mm0        ;make mask where sprite is transparent
        add     eax, 8          ;counter for sprite buffer
        pand    mm7, mm1        ;pixels of region under sprite to draw

        add     ebp, 8          ;inner loop counter
        por     mm7, mm0        ;combine sprite and background
```

```
        movq    [ebx], mm1      ;save background overwritten by sprite

        movq    [ecx], mm7      ;write sprite overlay results
        cmp     ebp, edi        ;done with current sprite row?
        jne     LoopTop
        add     ecx, edx        ;advance region to next buffer row
        xor     ebp, ebp        ;reset inner loop counter
        dec     esi             ;last row of sprite ?
        jnz     LoopTop

        pop edi
        pop esi
        pop edx
        pop ecx
        pop ebx
        pop eax
        pop ebp
        ret 0
_sprite_overlay ENDP
_TEXT ENDS
END
```